
Gaylord
SPEEDY BINDER
Syracuse, N. Y.
Stockton, Calif.

MICHIGAN

STATE HIGHWAY DEPARTMENT

LANSING

BULLETIN NO. 4

MACADAM ROADS

BY

FRANK F. ROGERS, C. E.,
DEPUTY STATE HIGHWAY COMMISSIONER.

MARCH, 1912.

TOWNSEND A. ELY,
STATE HIGHWAY COMMISSIONER.

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1912

MICHIGAN

STATE HIGHWAY DEPARTMENT

LANSING

BULLETIN NO. 4

MACADAM ROADS

BY

FRANK F. ROGERS, C. E.,
DEPUTY STATE HIGHWAY COMMISSIONER.

MARCH, 1912.

TOWNSEND A. ELY,
STATE HIGHWAY COMMISSIONER.

LANSING, MICHIGAN
WYNKOOP HALLENBECK CRAWFORD CO., STATE PRINTERS
1912

MACADAM ROAD BUILDING.

It has been said that no invention, except that of the steam engine, has contributed so much to the science of locomotion as the system of road making founded on the discovery by Macadam that angular fragments of hard rock sufficiently reduced in size, will, under the pressure of wheels, coalesce or bind together and form a water-proof compacted mass of stone with a hard surface.

One hundred years ago John Louden Macadam addressed a memorial to the English House of Commons setting forth his views of the best method of improving England's highways. This report made him Surveyor General of the Bristol district, where, about five years later, he began the construction of a system of roads that ever since has borne his name. It is the construction of these roads in the most approved manner and in such modernized forms as improved machinery has made possible that the writer will endeavor to discuss.

SURVEY AND PLAN.

The first requisite in the building or improving of any road is a well defined plan, either in the mind of the builder or, what is better, on paper in such intelligible form that any person who is competent to direct such work can understand it and lay out and build the road in accordance therewith. It is only when a well designed plan is followed that the best and most economical results in road building are attained.

The surveyor should determine and the plan should show the exact location of the road on the ground. To do so reference must be made to section lines and corners, or to some regular subdivision line and corner, so that any other engineer or surveyor can accurately locate the same, either on the ground or on a township plat. This means that each end of the road must be definitely located from a determinable point in some section, and the courses and distances between these points accurately measured and marked on the plans.

It is always best to make one hundred foot stations, noting all important objects, such as bridges, culverts, cross roads, etc., by stations with such plus readings as may be necessary. Stakes should be set along the sides, one row on each side parallel to the center line, and preferably twenty or twenty-five feet therefrom, so as to place them on the outer margins of the ditches or gutters where they will not be destroyed by ordinary traffic, nor so easily by grading teams. (See upper section Figure 1.)

Levels should be taken at each station as follows: (a) on the center line; (b) on the hub at each side stake; (c) on the bottom of each

ditch, if there are side ditches. Plus levels should be taken on railroad tracks, on the floors of culverts and bridges, in the beds of streams that serve as the outlets for road ditches, going far enough down stream to make sure that such outlet is adequate, and at such other points as the surveyor or engineer may deem necessary.

The plan and profile should be placed on the same sheet, projecting the plan vertically above or below the profile. Angles in the line may be indicated by broken lines, small circles or other symbols giving bearings, or angles and distances in figures, without attempting to lay out the courses with a protractor. The complete working profile should show by lines drawn to scale, as well as by figures: (a) the center cuts and fills; (b) the depth of each ditch or gutter from the hub stake adjacent thereto; (c) the vertical distance, up or down, from each side stake to the established center grade. Nothing less complete is satisfactory, for in most cases the work of grading will be placed in charge of a highway commissioner or his foreman without the assistance of an engineer. It is enough to show the elevation of grade line at change points with the percent of grade, plus or minus, between such points. One hundred feet to the inch horizontal and five or ten feet to the inch vertical are desirable scales, using standard cross-section paper having ten lines to the inch. Tracing cloth or paper is preferable for this work, so that blue prints can readily be made for the extra copies, which are always required for filing and for working plans on the road. This method makes sure that all copies are exact duplicates of the original.

GRADES.

On Michigan state reward roads the law requires that the steepest incline shall not exceed six percent, meaning a rise of six feet in each one hundred feet of length. It is desirable to keep the grades on macadam roads below that—even down to 3 percent or less—where the cost of grading is not burdensome.

Long stretches of unbroken grade are objectionable however, being more expensive to maintain than roads that are slightly undulating. Surveyors who insist on establishing such grades do their clients a two-fold injury—they unnecessarily increase both the first cost and the cost of maintenance. Grades that more nearly follow the lay of the land with vertical curves at change points make lines that appear more graceful and that seldom mar the landscape. When such grades are not steep enough to limit the size of loads, or cause excessive washing on the surface of the roadway, no valid objection to them can be raised.

To haul a load on a good level macadam road surface requires a tractive force equal to about 1/40 of the weight of the load. To this must be added 20 lbs. per ton for each added percent of incline. Thus, it requires more than double the power used on the level to haul a given load up a 3 percent grade and about 3½ times as much power to haul the same load up the 6 percent grade.

It is estimated that horses can exert one-tenth of their weight as a tractive force on continuous work and remain in good condition. But they can readily exert themselves for brief periods of time up to two, three, and even four times their daily average working capacity. With this in view, making proper allowance for the fatigue of the team due

to raising its own weight up the incline, it will be seen that short stretches of undulating grades, none of which exceed six percent, can not materially lessen the capacity of a macadam road.

GRADING.

The cost of grading depends upon the kind and amount of earth that must be handled and the distance it has to be moved. Where old roads have been regraded for the purpose of building state reward roads, the cost has usually run from $200 to $500 a mile, $350 being a fair average. Some hilly roads have been graded at costs greater than $2,000 a mile.

TOOLS REQUIRED.

For rather low turnpikes, no tool is so efficient as the road grader in skillful hands, although the plow and harrow are frequently required to put the road in shape for using the grader to advantage. On turnpikes with deep ditches, the flat, or Doan scraper, is an excellent tool. It is not intended to move earth far but will spread it evenly over the grade when rightly handled. The drag scraper is good for hauls up to 150 feet. Between that distance and 700 feet, wheel scrapers are best, but to use them economically there should be enough scrapers working, unless moving soft sand, to keep a snatch team busy; and, where the soil has to be loosened, another team on a plow. For hauls longer than 700 feet it is cheaper to use wagons.

DRAINAGE.

In most soils sufficient drainage is provided by building the ordinary turnpike with side ditches or gutters just large enough to provide for the free flow of such water as naturally comes to the road. In no case should deep unsightly ditches be cut along the roadside for the purpose of making fills. (See lower cut showing fill in Fig. No. 1). In clay soils the bottoms of the ditches should be not less than two feet below the crown of the road, unless supplemented by tile drains. Especial pains must be taken to provide all road ditches with free outlets having sufficient fall to remove all water to some distance from the road.

Tile drains are needed in all springy or water bearing soils. Four-inch land tile laid along the upper side of the road, either under the gutter or in the shoulder, to cut off the flow of water before it reaches the road bed will usually prove sufficient. An additional line of tile can be placed on the other side later if found to be necessary. If springs have their sources in the road bed itself, it will be necessary to lay diagonal branches of tile directly to them. It is usually advisable to cover the tiles to a depth of six inches or more with gravel, cinders, broken stone or other porous material; and, in very wet soils, the drainage will be facilitated by filling the entire trench with some such material. Wrapping the joints with tar-paper has not proven satisfactory to the writer. If anything is required, strips of muslin or burlap are preferable. Quicksand can be kept out of tiles by excavating enough below grade so that the tiles can be laid in a bed of gravel, which should completely surround them to a thickness of from six to eight inches. The gravel used should have the voids practically filled with smaller pebbles grading down to coarse sand.

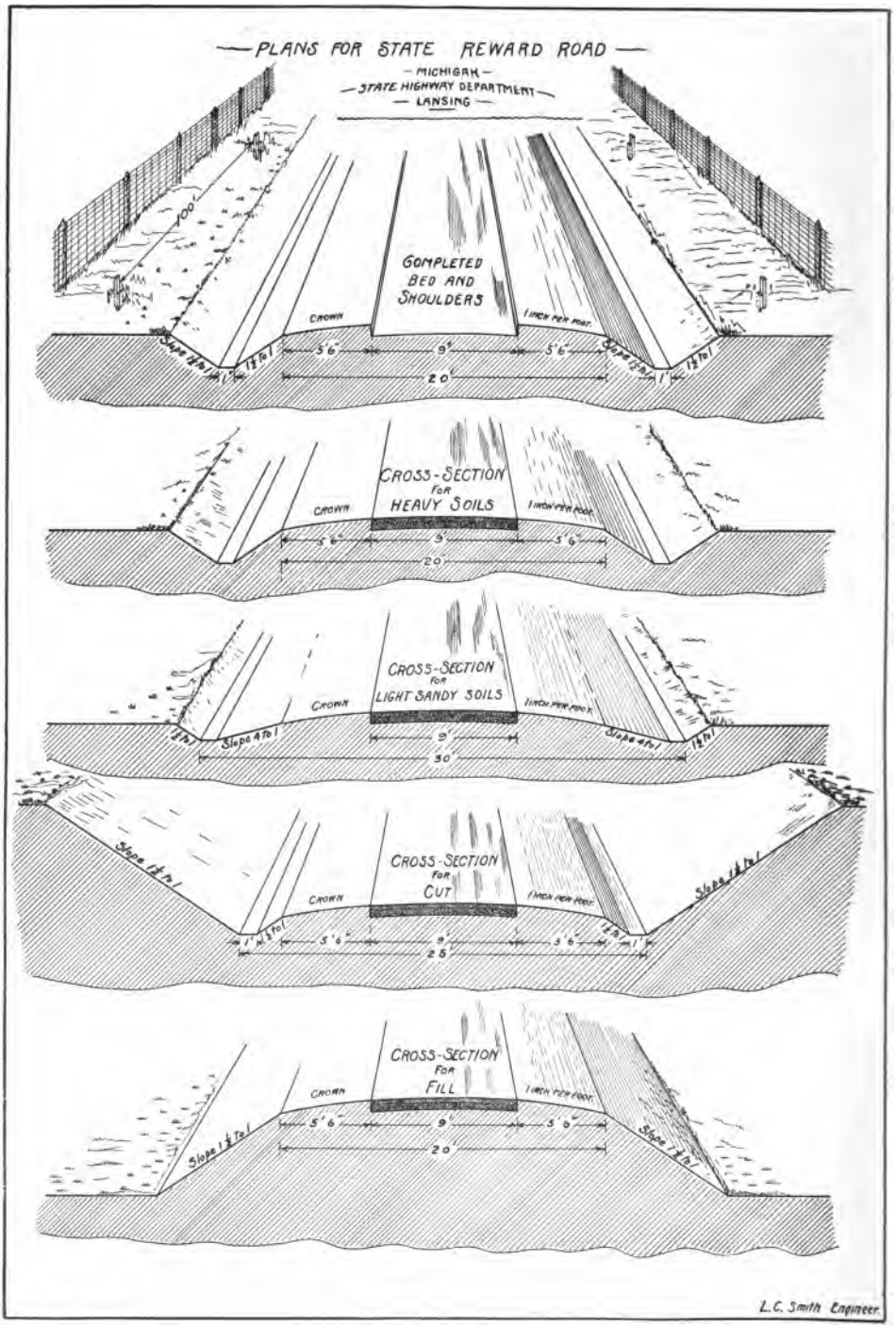
PLANS FOR STATE REWARD ROAD
MICHIGAN
STATE HIGHWAY DEPARTMENT
LANSING
100'
COMPLETED BED AND SHOULDERS
CROWN
1 INCH PER FOOT
Slope 4 to 1
1½ to 1
5'6"
9'
20'
CROSS-SECTION FOR HEAVY SOILS
5'
30'
CROSS-SECTION FOR LIGHT SANDY SOILS
CROSS-SECTION FOR CUT
25'
CROSS-SECTION FOR FILL
Slope 1½ to 1
L.C. Smith Engineer.

Figure No. 1.

In clay soils trenches should be cut through the shoulders described in the next paragraph, thus making outlets into the side ditches for water that may collect in the stone bed during construction, and afterwards until the surface becomes hard and water-proof. Such trenches should be 8 inches or 10 inches in width and slightly deeper than the stone bed. Where the foundation is soft or yielding, it is best to prepare the bed deep enough for an extra or sub-layer of some hard porous material, which is an excellent substitute for the old fashioned Telford base. This bed should be V-shape in section and filled with crushed stone, coarse gravel or small cobbles. The sub-base should be well rolled and properly shaped before the bottom layer of macadam is applied. In such cases the lateral trenches should be cut deep enough to draw the water from this sub-layer. (See Fig. No. 2.) These drains should be placed on both sides, in pairs, at every low point in the grade and, in very retentive soils, at intervals of not more than 100 feet.

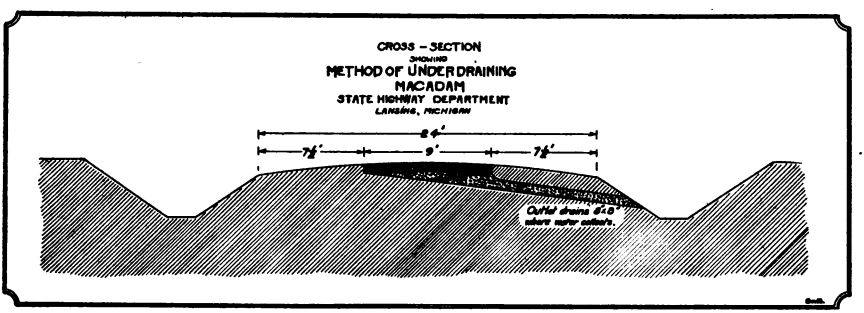

Figure No. 2.

On grades above 4% there is frequently much trouble caused by the washing or gullying out of the side gutters. This can be effectively prevented by paving the gutters with cobblestones or concrete. A cheaper method, which most always proves satisfactory, is to spread evenly over the bottoms of the gutters a three or four-inch layer of crushed stone, preferably that under 1½ inches in size. Coarse gravel has been used for this purpose with good results.

MACADAM BED AND SHOULDERS.

After the rough grading and draining just described have been completed, except the lateral stone drains above noted, the macadam bed should be formed in the central part of the road grade. This is done by placing shoulders of firm earth, or other suitable material, on each side of the center line and far enough apart to retain the proposed width of macadam, which, on Michigan state reward roads, must be at least 9 feet wide and not less than 6 inches deep after compacting. Any greater width and depth that the builders desire to make would be approved by the State but would not, under present laws, entitle the road to any greater bounty.

When the old road grade is as high or higher than the finished road should be, the shoulders are best formed by scraping earth from the center to each side with a road grader. But first, the road should

be leveled by driving the grader back and forth on the center of the turnpike with the blade set square across, so as to cut off the high places and deposit the earth in the hollows—using the grader as a planing tool. A double row of pickets set along the margins of the macadam bed, but one foot farther out so as to clear the hubs and whiffletrees, is a convenient method of marking out the grader work.

If the old grade is much too low, it is usually cheaper to regrade and turnpike before beginning to form the shoulders. But, where the old bed is about the right height for sub-grade, shoulders may be formed by bringing up earth from the sides with the grader, provided it can be spared from the gutters or ditches. In no case should the side ditches be cut deeper than good drainage requires. A common mistake is to excavate unnecessarily large and unsightly ditches along the roadside at the foot of a fill, for the purpose of forming the embankment. This is entirely unnecessary if the cuts and fills are properly balanced and should never be tolerated in highway work.

If enough earth cannot be spared from the sides adjacent to make the shoulders, it should be hauled with scrapers or wagons from other places where there is an excess, or taken from borrow-pits. Many places will be found where the center can be notched out, leaving the undisturbed sides for shoulders, and using the earth thus obtained to build up shoulders on slightly lower ground.

On sandy or mucky ground, it is often desirable to seek a better shoulder material. In such cases, any of the clayey or loamy soils are suitable, but a good packing gravel is better and should be used if practicable. A double layer of sods about one foot in width, placed grass side down along each margin of the stone bed, carefully laid to lines, and backed up with sand or other light soil, makes a very satisfactory shoulder. The writer has seen miles of macadam built over sandy soils with the sod-margin shoulder above described and knows of but few cases where there is any complaint from the spreading of the stone or from the shearing off of the edges of the macadam.

The shoulders thus formed should extend to the side ditches or gutters with the same grade and curvature as required for the finished road, viz: an average rise of one inch for each foot of distance from the inner edge of the ditches or gutters to the center line of the road. Thus, a twenty foot roadway would have a 10-inch crown and a 24-foot roadway a 12-inch crown. With this kind of road section, the drop at a point 5 feet out from the center line should not exceed 3 inches.

After the work above described has been completed, lines should be set up on the margins of the macadam bed and enough hand trimming done with mattocks and shovels to bring the macadam bed to the exact sub-grade, giving it the same width and curvature as required for the finished road. Due allowance must be made for settlement of the sub-grade by rolling. Crushed stone is far too expensive a material to fill hollows with, for they can be filled with earth from the shoulders at less than 1/10 the cost of broken stone, and every high point protruding into the macadam means a defective place in the finished road and hastens the day when repairs will be necessary. (See Figures Nos. 3 and 4.)

Figure No. 3.

Figure No. 4.

SUITABLE ROCKS FOR MACADAM.

A good stone for road building must be hard and tough, and the dust resulting from crushing and the wear of traffic, should have reasonably good cementing qualities.

In Michigan the most used road stones, in the order of their values, are: trap, cobblestones or field boulders, and limestone. The former is found only in the Upper Peninsula, and, thus far, has not been used on country roads except in the counties of Dickinson, Gogebic, Houghton, Keweenaw and Marquette, although some has been shipped to Detroit for park roads. There is no doubt that trap rock from Upper Michigan would be extensively used in the Southern Peninsula for the surface layer of macadam roads, if it were commercially available on a large scale, and at reasonable cost. Large outcrops of this rock are within one-half mile of Marquette prison and there is no good reason why this rock should not be crushed with prison labor and shipped to all our lake ports at a comparatively small price per ton. A large part of the limestone macadam used on the west side of the state is shipped across Lake Michigan from Wisconsin, and rock could almost as easily be shipped from Marquette if proper arrangements were made to supply the stone and transport it economically.

Cobblestones consist of a variety of rocks which range from the toughest traps down through the various grades of granites and limestones to a few sandstones, which are of no value to the roadbuilder. They are not uniformly distributed over the state, some sections having an abundance, while in other sections they are entirely wanting. Crushed cobblestones are not available on a commercial scale and are usually crushed with portable machines placed near where they are to be used.

CRUSHING COBBLES.

There is no difficulty in crushing cobblestones with portable crushers, where the best types of steel crushers are employed. Cast iron crushers and ordinary cast iron die plates are of little use for this work. For the most part, crushers having cast steel frames and equipped with manganese steel jaw plates have given the best satisfaction. In a few cases, some special makes of plates have given fairly good results. Traction engines rated at from 15 to 20 H. P. will easily drive any of these crushers. It is not economy to use a steam roller for this purpose. It is needed for rolling every day the crusher is running, and is too expensive a machine to wear out for power purposes.

The most satisfactory way to purchase cobblestones is by weight. From 13,500 pounds to 14,000 pounds are required for a cord, the weight being stipulated by the purchaser when the order is placed. Contractors figure that a cord of cobblestones will make 5 cubic yards of crushed rock measured in the different grades.

The labor cost of crushing cobblestone, including fuel and oil and small repairs, can usually be kept down to 30 cents per cubic yard under good management. If one figures repairs and depreciation, interest on the investment, etc., it would add approximately another 20 cents per cubic yard to the cost of crushing.

To prepare suitable sizes of broken stone it is necessary that the port-

able crusher be equipped with a rotary screen, the drum of which shall be not less than 9 feet long and 30 inches in diameter, consisting of three sections perforated to give the required sizes of metal. When crushing cobbles, the writer usually prefers to have these sections perforated with ¾-inch, 2-inch and 3-inch holes. Pieces of rock that are too large to pass through the 3-inch section, should be returned to the crusher and recrushed. Frequently a return belt conveyor is attached to the elevator, which does this work automatically. If the stone is so soft that too large a percentage of screenings passes through the ¾-inch holes, a ½-inch mesh wire screen should be placed around the plate screen and bolted to it, forming a jacket. To do this, 3-inch wooden blocks or pieces of small-sized gas pipe, three inches long, are placed between the plate and wire screens through which the bolts are passed. This leaves an annular space between the two screens, which are so adjusted that the small stones passing through the plate screen and over the wire screen are discharged into the second pocket of the storage bin together with the 2-inch stone. On the other hand, if too much dust is produced as might be the case with limestone, a ¼-inch mesh wire screen attached as above described, may be used as a dust jacket and the dust spouted into a special pocket from which it can be hauled away and wasted. This might result in a scarcity of binder, as only that part of the product passing through the ¾-inch screen and retained on the ¼-inch screen could be used. In such a case it would be necessary to have the first section of the screen perforated with 1-inch holes, instead of ¾-inch holes.

From the above it will be noted that three grades of stone are provided which are discharged into separate pockets of the storage bins. From these they are drawn by gravity directly into the wagons in the order they are to be placed on the road. The fine stone is commonly called "screenings" or "binder," but for convenience the different grades are usually designated by the numbers 1, 2 and 3—number 3 being the largest size. (See Figures Nos. 5 and 7.)

Limestone, which is used for building most of the macadam roads in Michigan, is usually bought from the large commercial crushing plants, broken to such sizes as the work requires and delivered by boat or rail at points within teaming distance of the proposed road.

FIRST COURSE OF MACADAM.

After the macadam bed and shoulders, with sub-base and special drains where needed, have been prepared as already described and well compacted by rolling, the first course of No. 3 stone is laid. This must cover the bed to such uniform thickness as will make the depth not less than 3½ inches after rolling, say 4½ inches loose measure. If a harder and more expensive stone is to be used for the surface, the bottom layer may be increased to 5 inches loose measure and the top layer thinned accordingly.

Pains must be taken in placing the stone on the road to make sure that the different sizes are well mixed. Alternate patches of large and small-sized stones will not make a road surface that wears evenly. Unless automatic spreading wagons are used, it is best to make three or four dumps of each load, so that the least possible amount of handling

with rakes and shovels will be required. In no case should this layer be put on a muddy bed. After the stone has been spread as above described, it should be rolled two or three times over with a power roller weighing about 10 tons and then covered with No. 1 stone (screenings) to a uniform depth of about ¾-inch and rerolled. The rolling should commence on the edge of the stone with about half of the outer rear wheel of the roller lapping on the earth shoulder, and gradually lapping towards the center as the rolling continues. As soon as one-half of the roadway is thus rolled the roller should be run off the stone and started on the other side which should be rolled in the same manner finishing at the center. Any other method will soon destroy the crown of the road. (See Figure No. 3.)

The amount of screenings used should be somewhat less than enough to fill the voids in the No. 3 stone. Water may be applied in advance of the roller when working on sandy soils but not until the roller has passed a few times over the dry screenings. But water should be used sparingly, if at all, on the No. 3 stone when building over clay and loamy soils on account of the tendency to form mud on the subgrade, into which the stone are driven by the roller. Water is beneficial, however, and is usually a necessity on sandy soils to prevent the sand from mixing with the stone. The rolling of this course must continue until the binder is all worked into the crevices of the larger stones and until the stones cease to sink or creep beneath the roller. If hollows develop by reason of this rolling, they should be filled with suitable stones of the same grade and not with screenings.

If commercial limestone is used, it is better to use stone that will range from 1½ to 3 inches in their greatest dimensions, and to use the same grade of stone for both the bottom and top layers, but it is very important that the stone shall be evenly mixed when spread upon the road. When limestone screenings are used for binder, only those from which the dust has been removed should be accepted. Plenty of dust for cementing purposes will be formed under the roller, and, when the road is once consolidated, the less dust on the surface the better. This dust is a nuisance in dry weather and makes a disagreeable mud when the weather is wet.

SAND SUB-GRADES.

Before placing the first layer of stone on dry mealy sand sub-grades, it is often necessary to spread a thin layer of marsh hay, rotten straw or some other vegetable fibre over the entire stone bed to prevent a large part of the No. 3 stone from being driven into the sand so deeply that it is of little value except as a sub-base. An extra layer of stone rolled into the sub-grade makes a foundation equally as good or better than the materials above mentioned, but the cost of the stone usually makes this latter method so expensive that it is prohibitive.

TOP COURSE OF MACADAM.

After the first course of macadam has been applied and bonded and rolled as above described another layer of stone must be added and of such uniform thickness as to make the total compacted depth of the

road at least 6 inches, if it is expected to draw state reward. If the first layer was 4½ inches loose depth the top layer must be at least 3½ inches deep, or, if the first layer was made 5 inches thick the top layer may be reduced to 3 inches. The stone used in this layer will be that known as No. 2, which passed through the 2-inch perforations of the crusher screen and was caught in the second pocket of the elevator bins. However, should limestone from the commercial quarries be used, it is better to purchase stones ranging from 1½ to 3 inches in size, as already specified for the first course of macadam. Stones of this size wear much better, are not easily dislodged and left in a loose condition on the road bed, nor so easily picked up by the mud that adheres to the wheels of vehicles. Some engineers have placed the No. 2 limestone in the bottom layer and the No. 3 limestone in the top layer, and the results are reported to be very satisfactory. But this is not necessary unless the whole product of the crusher must be used, which is not true when crushed stone is bought from the large quarries. What was said about the manner of spreading stone for the bottom layer applies with equal force to the top layer.

When the stone for the top layer has been spread as above described, it shall be rolled until smooth with a 10-ton power roller, after which screenings (No. 1 stone) will again be applied to the uniform depth of about ¾ of an inch and rolled a few times over before wetting. From this on, water must be applied freely from a horse sprinkler and the rolling continued until the water flushes to the surface. As the rolling progresses, the screenings will disappear in patches, when more screenings will have to be added until all the voids are filled and a very thin coating of screenings covers the surface.

In no case should the screenings be dumped in piles on the loose stones. When this is done, the screenings are never evenly spread and many of them are wasted. Too many screenings are detrimental to the road as well as a total waste of the most expensive part of the road covering, particularly if made from hard stone. Unless the screenings can be spread evenly with automatic spreading wagons, it is best to place them on the shoulders along the sides of the roadway and spread them carefully by hand. Pains must be taken to apply the screenings evenly mixed. Casting crosswise of the road with shovels invariably places the chips on the far side and the dust on the side where the spreader stands. This can be overcome by casting lengthwise of the road with a swinging motion of the shovel.

The manner of rolling described for the bottom layer applies equally to the top layer. In the final rolling, however, the whole surface of the roadway, including the shoulders, must be covered. Hollows that may have developed in the shoulders must be filled, and high places leveled down and the process of leveling and rolling continued until the whole road grade from gutter to gutter is so firm and smooth that water will flow to the side drains without obstruction. Figure No. 4 shows both layers of stone and a steam roller at work.

After the thorough watering and rolling above described has been completed, the road should be kept closed to traffic until the surplus water has dried out, when the road, if well constructed, will have taken a "set" and become so hard that it will have a metallic ring when driv-

Figure No. 5.

Figure No. 6.

ing over it and small pieces of rock will crush under a heavy load before penetrating the surface.

The amount of rolling and water required are much more than the inexperienced road builder will expect. Gillette estimates that about 4 cubic feet of water are required for each cubic yard of compacted macadam to properly "puddle" the screenings or binder. That is equivalent to about 900 barrels of water for each mile of 9-foot macadam roadway, which is no small item of cost if the water is not very handy. If the water is not used to the best advantage more will be required.

A steam roller cannot compact more than 50 to 75 cubic yards of crushed rock daily. That is about the output of the ordinary portable rock crusher and means that from 20 to 30 days of steady rolling are required to properly consolidate a mile of state reward macadam road. For completed macadam road see Fig. No. 6.

COST OF MACADAM ROADS.

The average cost of macadam roads in Michigan is running slightly less than $4,500 a mile. Some roads have been built for less than $3,000, while others have cost more than $8,000 per mile. The higher costs usually mean that the grading cost was high, or that the width of macadam was made greater than 9 feet.

Every road is a problem by itself, depending on so many local conditions that averages are of little satisfaction to a person desiring to know the actual probable cost of a given road. As the grading cost, the material cost and the distance the material has to be hauled are the three items subject to greatest variation, a model estimate will be given on which the above items will be taken at fair assumed values, so that they can be changed by anyone desiring to make other estimates that will fit different conditions and places where these values have been determined.

First, we shall assume that crushed limestone is to be purchased from a commercial quarry and delivered f. o. b. cars at some siding within a wagon haul of the proposed road. The estimates are as follows:

Grading, per mile	$350 00
1,200 cu. yds. crushed stone 1½ to 2 in. in size at $1.40	1,680 00
300 cu. yds. screenings with dust out at $1.40	420 00
Loading and hauling 1,500 cu. yds. stone one mile at $.45	675 00
Spreading same $.05	75 00
Sprinkling and rolling, 25 days at $15.00	375 00
Superintendence and contingencies	200 00
Total	$3,775 00

If crushed cobblestones are used, 300 cords to the mile will be required. These should crush into 1,500 cubic yards, measured in the different grades. The crusher should be set but once for each mile of road and as near the center of the mile as is practicable. In this case, the stone cost at $4.00 per cord would be as follows:

300 cords cobbles at $4.00	$1,200 00
Crushing 1,500 cu. yds. at $.50	750 00
Hauling 1,500 cu. yds. of stone to the road (no shoveling into wagons required) at 30c	450 00
Total	$2,400 00

This shows a saving on stone delivered to the road of $375.00 and we may assume that the other items will remain the same. In such a case, one would be justified in paying $5.25 per cord for cobbles delivered at the crusher, as compared with commercial stone at $1.40 per cubic yard on cars one mile from the road.

The following cost is taken from a Michigan state reward road built in Golden township, Oceana county, by Fred Urtel, Township Highway Commissioner.

Grading	$237 40
301½ cords cobbles at $4.00	1,206 00
Crushing same	547 87
Hauling stone from the crusher and spreading on the road.	500 20
Rolling and sprinkling	208 12
Superintendence and plans	162 12
Total	$2,861 71

The above cost is very low and does not include profits to any one, nor rental or depreciation for the machinery used, as it is all owned by the township and the work was performed by day labor under the direction of the township commissioner. It does include, however, the cost of moving the crusher from a former location and erecting it on the job, as well as fuel and oil and other incidental expenses. It might be further said that the finished road was a credit to its builders.

Figure No. 5, shows the crusher at work on the above road, and Figure No. 6, further illustrates the methods employed in crushing cobblestones. The former shows a home-made bin and the latter a portable bin on trucks. Note what is said about using the roller for power purposes on page 9.

BITUMINOUS BONDED MACADAM.

The advent of the automobile has brought a new and destructive agent to the ordinary water-bound macadam highway. Rapidly driven motor cars propelled by the friction of pneumatic tires on the road surface have added two new and destructive forces that heretofore have not had to be taken into account by the road-builder. The suction of the tires added to the shearing action on the surface by the drivers destroys the ordinary macadam in a short time. In fact, macadam roads that had resisted the ordinary horse-drawn-vehicle traffic, with but little wear for many years, have gone to pieces rapidly under the automobile.

To overcome this trouble many localities are now resorting to a bituminous bonded surface, and, in most instances, where the most

Figure No. 7.

approved methods are used, with fairly good results.

The term bituminous is used interchangeably as referring both to asphalt and tar products. Generally speaking, present approved practice has settled down to three methods of using these materials.

(1) As a surface treatment for old or newly laid water bonded macadam on which a surfacing is needed, both as a dust layer and a surface coating which holds down the binder and bonds the surface stones sufficiently to prevent them from getting loose under the shearing and suction action of the rubber tires of rapidly driven motor cars.

(2) As a binder by the penetration process for the top layer of No. 2 stone before the screenings are applied.

(3) As a binder by the mixing process for the top layer of No. 2 stone.

SURFACE TREATMENT.

Where the surface treatment is used on old roads, they should first be thoroughly cleaned by removing all dirt, dust or other foreign material. All hollows should be filled with No. 2 stone or rather coarse chips which have previously been coated with the bituminous mixture. The day before the bitumen is applied, the road should be thoroughly sprinkled. It is well to sprinkle in the afternoon and apply the bitumen the next morning, after the water has been absorbed by the road surface, but before the surface has dried. Charles Ross, Superintendent of Streets, of Newton, Massachusetts, who has had much experience with bituminous materials, says that the wetting will cause the oil or tar to adhere, when, if it were spread on a layer of dust, no matter how thin, it will separate and roll up on the wheels of vehicles.

The bitumen may be applied by hand with sprinkling cans having fan shaped nozzles, with horse sprinklers having distributing devices adapted to the purpose, or what is still better, with pressure distributors that apply the bitumen as a fine spray. One-half gallon to the square yard is usually sufficient for a surface application on hardened road surfaces. It is generally admitted that two applications of ¼ gallon each are better than to put on the full amount at a single application. This cannot be done unless a pressure distributor is used.

A few hours after the bitumen has been applied, the entire road surface should be covered with stone screenings or pea gravel to a depth of about ¼-inch, or in sufficient quanities to absorb any surplus oil or tar. The next day, the road can be safely opened to traffic.

If a new macadam road is to be thus treated, it should first be thoroughly consolidated by watering and rolling, as specified for the ordinary water-bound macadam, then allowed to dry out, when it can be treated as above described. Many engineers prefer that such a road should be traveled several months, or even a year, before the bituminous surface is applied.

The lighter oils, meaning those that can be applied without heating, are used more for dust layers than binders, but much that has been specified above will apply equally well to the manner of using these oils.

PENETRATION METHOD.

When the penetration method is used, the layer of No. 2 stone should be put on a base in which the voids are completely filled so as to pre-

vent the loss of bitumen by seepage into the lower layers. This can be done by using more than the usual amount of screenings and thoroughly compacting the bottom layer, supplementing the screenings with fine gravel or coarse sand if necessary to make the desired bond and finish. More watering and rolling will be required than is commonly given the bottom layer.

After spreading on a bed thus well prepared, the No. 2 stone should be coated as thoroughly as possible by the means employed with a heavy bituminous binder applied hot, usually at temperatures ranging from 250 to 300 degrees F. The bitumen may be applied by any of the methods described for surface treatment, but the pressure distributor is always preferable.

Heavy asphaltic bitumen should contain about 90% of asphalt. If the refined tars are used, they should be of such purity and consistency as will give them equal binding powers to asphalt, but without brittleness which is always detrimental to a bituminous binder. From ¾ to one gallon per square yard is usually required for the first application, after which stone chips ¾-inch in size (stone screenings from which the dust has been removed) should be evenly spread over the surface to the depth of about ½-inch and rolled in. After this rolling a second application of heated bitumen will be required, using from ¼ to ½ gallon to the square yard, which should be thinly covered with pea size stone or fine gravel and lightly rolled, or allowed to work in under traffic. The road can be opened to travel the next day after finishing.

MIXING METHOD.

The mixing method is used more for city streets or suburban roads near large cities, where considerable money is available for road building purposes. This method is commonly conceded to be the best, but for the reasons above stated, it has not been so extensively used as the others.

The heavy bitumens, containing about 90% of asphalt, or correspondingly heavy tars, are required for this purpose. The stone to be coated is usually heated and mixed with the bitumen, either by hand after the "sweat board" plan of mixing concrete, or in suitable mechanical mixers. Concrete mixers, both of the continuous and batch type have been successfully used for this work, but the best results can be produced by using a regular asphalt batch-mixer of standard pattern.

The foundation for this bituminous concrete top may be ordinary water-bound macadam, old or new, or a regular concrete base similar to that used under brick pavements. The success of this form of pavement, like all others, is largely dependent on the stability of its base.

The bituminous macadam top should be at least 2 inches thick after thorough rolling, and thicker where the traffic is very heavy. At least 25% will have to be allowed for compacting. The crushed stone used for the top should all be fine enough to pass through a 2-inch mesh screen and should include all sizes down to screenings, from which the dust has been removed. This stone should be evenly mixed, the smaller sizes as completely filling the voids in the larger ones as possible. The more nearly the voids have been filled, the better will be the results. Coarse sand and fine gravels are sometimes added to fill the voids more completely than is possible with clear stone.

Crushed stone can be more evenly heated in some of the forms of rotary heaters now on the market. Several other forms are said to be successful. The writer has used ordinary scrap boiler iron, raised sufficiently from the ground by means of bricks or stones to allow placing a fire under the plates, on which the stone was piled and turned with hoes and long-handled shovels until sufficiently heated. After heating, the stone may be wheeled or drawn to the mixer in wagons.

It is now said that the same results can be produced by washing the stone with crude gasoline, using about 12 quarts of gasoline to a ton of stone. This is accomplished by first charging a batch mixer with the stone, then throwing in the gasoline, which is evaporated after a few turns of the mixer, when the bitumen can be added and the mixing completed. Only enough bitumen should be used to thoroughly coat each fragment of stone. From 8 to 10 gallons of bitumen to the ton of stone should be sufficient. An excess of bitumen is always detrimental. When the bituminous-concrete top has been applied and rolled, it is necessary to again coat the surface with a thin covering of the same kind of liquid bitumen applied hot, at the rate of about ¼ gallon to the square yard, after which the pavement is covered to the depth of ¼-inch with stone screenings, pea gravel or coarse sand and lightly rolled. When thoroughly set the road can be opened to travel. This is usually the next day after finishing.

The cost of roads, on which bituminous materials are used, generally exceeds the cost of ordinary water-bound macadam by from 12c to 50c per square yard of road surface treated, varying with the methods employed. Many miles of Michigan roads have been coated with light asphaltic oils, applied cold, at a cost of about 2c per square yard. A single treatment lays the dust and usually saves the road from disintegration for one season.

APPENDIX.

GENERAL SPECIFICATIONS FOR ROADS—CLASS E.

Section 10, Chapter V, Act No. 283, Public Acts 1909, as amended.

If the work is to be done by contract, write the State Highway Department for blank forms for bids, contracts and bonds. They will be furnished without charge.

This specification covers only water bound macadam. If bituminous binder is to be used, a special specification must be furnished by or approved by the State Highway Commissioner.

GRADING.

The roadway shall be graded so as to strictly conform to the plans and specifications for the road in question, heretofore submitted to and approved by the State Highway Commissioner. The finished road shall be not less than twenty feet between and exclusive of side ditches or gutters, and have a cross-section oval in form, with an average rise of one inch to the foot from the inner edge of such ditch or gutter to the center line of the road. Twenty feet is too narrow for the roadways of heavily traveled roads, and the State Highway Department recommends that turnpikes be made from twenty-two to twenty-four feet wide where the travel is heavy. For more details as to manner of forming grades and itches see cut on page 6.

DRAINAGE.

The side ditches and gutters shall be of such size as the drainage requirements of the locality demand, and must be formed with true grades having sufficient incline to cause a free and uniform flow of water to the nearest natural outlets, which outlets must be so improved where necessary as to carry the water quickly away from the highway. The slopes of the banks of ditches shall be not steeper than one and one-half horizontal to one vertical.

Tile drains shall be laid where needed at such places, of such kind and size, and on such grades as may be shown on the plans.

In clay soils trenches shall be cut through the shoulders, one on each side, described in the next paragraph, making outlets into the side ditches for water that may collect in the macadam bed during construction and later before the surface becomes hard and water-proof. Such trenches shall be eight inches or more in width and slightly deeper than the macadam bed. They shall be placed at all low points in the grade, and not farther than one hundred feet apart in retentive soils, and must be filled with crushed stone when the first layer of macadam is being applied.

MACADAM BED AND SHOULDERS.

After the road has been graded as above described the macadam bed shall be formed in the center part of the road grade as follows: Shoulders of firm earth, or other suitable material, shall be placed on each side of the macadam bed, not less than nine feet apart, or such greater distance as may be required to retain the width of macadam specified. The shoulders shall extend to the side ditches or gutters at the same grade and curvature as required for the finished road. Where the road grade is high, the shoulders may be formed by moving earth from the center of the present road grade to the sides or, if the grade is low, by crowning the present road grade by scraping earth from the sides toward the center or, if sufficient suitable material cannot be had along the roadway, it shall be brought from other places along the line of work.

ROLLING SUB-GRADE.

After the shoulders and macadam bed have been formed as above described the whole roadway shall be rolled until no more compacting is possible. The hollows developed by this rolling shall be filled with suitable material under the direction of the officers in charge, and the roadway again rolled, and left in solid and firm condition, everywhere parallel to the finished roadway, the macadam bed being six inches below the finished grade and having the same crown. In deep mealy sand, where rolling is impracticable when sub-grade is shaped, marsh hay, rotten straw or fine brush shall be laid on the sub-grade to prevent the first course from mixing with the sand.

FIRST COURSE OF MACADAM.

To secure the product in sizes to comply with these specifications the crusher shall be equipped with a revolving screen not less than nine feet long and thirty inches in diameter, having perforations as follows: First section, three-quarter-inch holes; second section, two-inch holes; third section, three-inch holes. Any stones not small enough to pass through the three-inch holes shall be returned to the crusher and re-crushed.

After the road has been graded and rolled in the manner above described, a layer of crushed stone shall be spread on the prepared bed to such uniform thickness as to be not less than three and one-half inches deep after thorough rolling, four and one-half inches deep loose measure. The stone for this course may be a suitable grade of crushed limestone, cobbles or trap rock, and shall consist only of that part of the crusher product passing over the three-quarter inch section and through the three inch section of the crusher screen. This stone shall be placed upon the road uniformly mixed, no patches of alternately large and small stones being allowed. Unless automatic spreading wagons are used, this is usually best accomplished by making several dumps of each load so that the least possible amount of handling with shovels and rakes will be required. In no case shall this course be laid on a muddy sub-grade.

BINDER FOR FIRST COURSE OF MACADAM.

After the stone has been spread as above described, it shall be rolled two or three times over with a roller weighing not less than ten tons, after which it shall be covered to the uniform depth of from one-half to three-quarters of an inch with stone screenings and re-rolled. The amount of binder used shall be somewhat less than enough to fill the voids in the stone. Water may be applied in advance of the roller after the binder is added, if ordered by the officers in charge, but it should be used sparingly on clay sub-grades. The rolling must be continued until the binder is worked into the crevices of the larger stones and the stones cease to sink or creep beneath the roller. If depressions are formed they shall be filled with stones of suitable grade, and not with screenings.

Stone screenings used to bind this course may be that part of the crusher product passing through the three-quarter inch section of the crusher screen when crushing the stone used for this course.

TOP COURSE OF MACADAM.

After the first course of macadam has been applied, bonded and rolled as above specified, another layer of crushed stone shall be added, of such uniform thickness as to be not less than two and one-half inches deep after thorough rolling, three and one-half inches deep loose measure. The stone for this course may be a suitable grade of crushed limestone, cobbles or trap rock, and, in case of cobbles or trap rock, shall consist only of that part of the crusher product passing over the three-quarter inch section and through the two inch section of the crusher screen except for binder as hereinafter specified. When limestone is used for this course, it shall consist only of that part of the crusher product passing over the three-quarter inch section and through the three inch section of the screen. This stone shall be placed upon the road uniformly mixed, no patches of alternately large and small stones being allowed. Unless automatic spreading wagons are used, this is usually best accomplished by making several dumps of each load, so that the least possible amount of handling with shovels and rakes will be required.

BINDER FOR TOP COURSE OF MACADAM.

After the stone has been spread as above described, it shall be rolled two or three times over with a roller weighing not less than ten tons, after which it shall be covered to a uniform depth of about three-quarters of an inch with stone screenings. The screenings, when cobble or trap rock, may consist of that part of the crusher product passing through the three-quarter inch section of the crusher screen when crushing stone for the macadam top. When limestone is used for the binder, the product shall consist of limestone chips, ranging in size from three-quarter inch down, from which the dust has been removed. The amount of screenings used must completely fill the voids in the larger stones. After the screenings are added, water shall be applied with a horse sprinkler and the road rolled and watered until it becomes so hard that a piece of rock will crush beneath the roller before penetrating the